research review

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SOLAR "DISHPAN" EXPERIMENT

SPACE PHYSICS LABORATORY, AFCRL

In a laboratory experiment, AFCRL hopes to simulate the general magnetic field of the sun and its rotating corona. The experiment uses fluids to simulate the conducting gases of the photosphere (the visible disk of the sun) and the solar corona. It is called a "dishpan" experiment--a term borrowed from meteorologists who sometimes use liquids in containers to study climatological phenomena.

Behind the AFCRL experiment is the assumption of a dynamo current in the photosphere. The experimental apparatus itself has two basic parts. The first is a large magnet capable of a uniform 250- to 1500-gauss field over a volume of three cubic feet. It can be rotated 360 degrees. Within the magnetic field are two containers, one of which fits inside the other. Several container geometries are being investigated. One consists of two cylinders. Another consists of a smaller sphere inside a larger one. These containers can rotate at various speeds relative to one another. In each container there is placed a conducting fluid of a specified viscosity. The fluid in the inner container has conducting and viscosity properties simulating those of the photosphere. Surrounding the inner container is a larger container with a fluid of different conducting and viscosity properties.

One of the first things that we learn in physics is that, whenever an electric charge is in motion, you have an electric current and, when you have an electric current, you have a magnetic field associated with it. When you move a magnetic field relative to a conductor, you induce a flow of current. These relationships go back to Ampere and Faraday in the 1820's, and are the bases of the AFCRL experiment. They go into the commonly accepted explanation of the earth's magnetic field. The low convective movements of the earth's liquid core produce electric currents--and these in turn produce the earth's main magnetic field.

The total magnetic-field structure of the sun is much too complex to be replicated in the laboratory. Magnetohydrodynamics come into play as a complicating factor. The AFCRL experiment involves simple electrodynamics. Marvin L. White of AFCRL, who is conducting the experiment, is interested only in the general solar magnetic field and the solar

corona, both of which extend throughout the interplanetary system. He is not concerned with the multitude of highly intense, sometimes transient, localized solar magnetic fields.

The key aspect of the experiment is approximating the relative angular velocities of gases within the photosphere and the solar corona. Although both the photosphere and the solar corona are made up of gases, their comparative densities make them, in effect, two distinct entities.

Experiments to date have been mostly concerned with hydrodynamic effects of fluids with various viscosities. In one experiment, Karo syrup was used; in another, glycerin was tested. These tests are made at various rotational speeds of the containers, speeds ranging from 200 to .049 rpm. By simply adding sulfuric acid to the fluids, it is possible to vary their conductivity over a wide range.

White has delineated the photosphere as a transition region both from a mechanical and from an electromechanical point of view. Because of the high Reynolds number (in fluid mechanics, the ratio of the inertia force to the viscous force) in the photosphere, there is considerable slippage. The angular velocity should drop considerably from the solar interior to the outer photosphere when magnetic effects are neglected. On the other hand, the corona rotates as a nearly solid body out to great distances.

When the conducting fluids are rotated in a container in the presence of a magnetic field, it is possible to derive information on the current system set up by the resulting dynamo action. Primary measurements will be made of the electromotive force (e.m.f.) of the current. The AFCRL experiment is the first one to our knowledge in which conducting fluids are used to simulate astronomical phenomena. ★

research review
OFFICE OF AEROSPACE RESEARCH

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JACOB SEIDEN
Editor

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NUCLEAR REACTIONS AND INTERNAL CONVERSION ELECTRONS

HANS J. HENNECKE
General Physics Research Laboratory, ARL

A major goal for an experimental physicist engaged in nuclear-structure research is to obtain detailed information about the excited states of selected nuclei. Such data can then be used to provide a significant test of present and future nuclear models and theories. The field of nuclear-structure physics has advanced to the point at which a wealth of survey-type data covering a broad range of nuclei is available. However, detailed information about levels in any particular nucleus up to an excitation, say, of 10-MeV, is not generally known.

The three basic properties of nuclear levels, viz., energy, spin, and parity, can often be obtained by measurements which are essentially nuclear model independent. Such measurements are based either upon very general conservation laws or upon the use of a well-known interaction such as the electromagnetic interaction. This type of interaction can also provide data about the electromagnetic decay properties of nuclear excited states. Such properties include the lifetime or level width, the branching of the decay to several lower excited levels, and the mixing of the angular momentum carried off by the radiation field. The mixing referred to here arises from the fact that the angular momentum of the radiation field is not a good quantum number in the present situation. That is, there are in general several possible discrete values of the angular momentum of the radiation field which are consistent with the conservation of angular momentum of the whole system.

Until quite recently nuclear-structure research was divided into two broad areas: the study of the light-to-medium-mass nuclei ($0 < A \leq 50$) by means of accelerator-induced nuclear reactions, and the study of heavy nuclei ($A > 50$) by means of radioactive decay. Of course certain techniques were applicable over the whole mass region; especially low-energy neutron capture studies. The development of the tandem accelerator has now opened up the region of heavy nuclei for exploitation by the more versatile techniques of accelerator-induced nuclear-reaction studies. The radioactive decay work has provided very useful information; however, such studies are hampered by the inherent inflexibility of the radioactive decay process. The ability to use an accelerator to excite preselected individual nuclear levels is certainly a tremendous aid to the experimenter. The increase in level density with increasing mass puts stringent requirements on the energy resolution of accelerators used in the study of heavy nuclei.

The higher-level density in heavy nuclei puts equally severe limitations on the energy resolution of the detectors used to investigate the nuclear-reaction products. This limitation is felt particularly strongly by those investigators interested in the electromagnetic decay properties of nuclear levels. In the light-to-medium-mass region, such properties have been investigated by means of gamma-ray spectroscopy. Unfortunately, the most versatile gamma-ray detector, a Na I (Tl) crystal coupled to a photomultiplier tube, has a rather poor energy resolution, typically 8-9%. Currently, lithium-drifted germanium crystals are being developed which promise as much as two orders of magnitude improvement in resolution at the expense of several orders of magnitude in efficiency.

Over the years accelerator-oriented nuclear spectroscopists have come to the realization that one technique utilized by investigators in the field of radioactive decay of heavy nuclei has not been fully exploited. This technique is the investigation of internal-conversion electrons by means of a high-resolution magnetic-deflection spectrometer. A cursory search of the literature for the past 10 years or so indicates only a handful

of investigations utilizing the internal-conversion process to study accelerator-induced nuclear reactions (1). The paucity of such studies results from the low efficiency of the internal-conversion process for light nuclei, plus the generally low-beam currents available from high-resolution accelerators.

The process of an internal-conversion transition is analogous to the Auger transition process discussed in a recent OAR Research Review article (2). In the case of an atomic Auger transition, an excited atom with an electron vacancy in an inner shell (usually the K-shell) de-excites by a rearrangement consisting of an electron from an outer shell (say the L_1 subshell) filling the original vacancy, while another outer-shell electron (from the L_3 subshell, say) is emitted from the atom. The interaction responsible for such a process is the electrostatic interaction between the two outer-shell electrons. For the case of an internal-conversion transition, a rearrangement of the nucleons within the nucleus results in the direct emission of an electron from one of the atomic shells. No intermediate gamma ray is emitted by the nucleus and absorbed by the atomic electron.

For so-called electric transitions, the process results from the coulomb interaction between the atomic electron and the protons of the nucleus. More generally, the process is due to the full electromagnetic interaction between the atomic electron and the nucleons. In general, only electrons of the innermost atomic shells contribute significantly to the process, since the electromagnetic interaction varies as some power of $1/r$, where r is the separation of the electron from the nucleons.

Internal-conversion electrons are important not only because their energies can be measured with high-resolution magnetic spectrometers (resolution of 0.4% in energy is not uncommon for such instruments), but also because they can yield nuclear-model-independent information about the electromagnetic decay of nuclear levels. The basic parameter in this work is the internal-conversion coefficient α, defined as the ratio of the number of internal-conversion electrons N_e corresponding to a particular nuclear transition emitted from a source per unit time (or per unit amount of integrated beam current striking the target) to the number of gamma rays N_γ per unit time corresponding to the same transition. Such a coefficient can be defined for electrons emitted for any of the atomic shells or subshells, viz. α_K, $\alpha_L = A_{L_1} + \alpha_{L_2} + \alpha_{L_3}$, α_{L_1}, etc. Both the K-coefficient α_K and the K/L ratio α_K/α_L depend on the multipolarity of the electromagnetic interaction, i.e., on the parity and angular momentum of the electromagnetic interaction. Consequently, these coefficients give information on the spins and

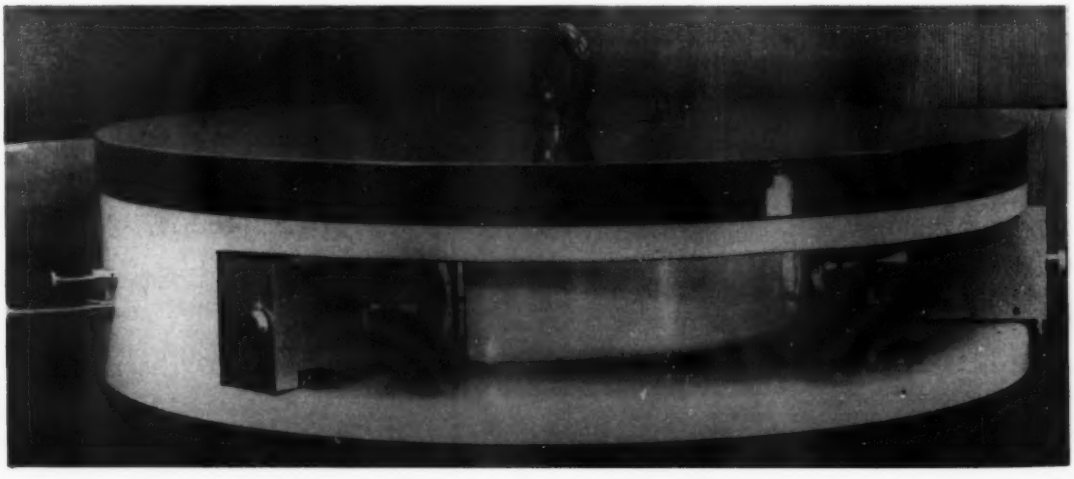

FIG. 1. Double-focusing beta-ray spectrometer.

parities of the two nuclear levels connected by the transition plus the mixing of the transition.

Extensive tabulations of calculated internal-conversion coefficients are presently available. These calculations include relativistic effects, screening effects caused by the presence of the other electrons of the atom, and finite nuclear-size effects (4). The finite size effects, while appreciable (50% for M1 transitions), are rather insensitive to detailed assumptions about the nuclear-charge density. It should also be mentioned that, in some cases, the internal-conversion coefficient can be altered significantly by dynamic nuclear-structure effects. Such effects are not included in the above-mentioned tabulations; they are important mainly for certain retarded transitions (5).

The Nuclear Group at ARL is presently installing a high-resolution iron-core beta-ray spectrometer (Fig. 1) of the $\pi\sqrt{2}$ double-focusing type designed by Prof. K. Siegbahn (3) of the University of Uppsala, Sweden. This instrument will be used initially with a 2-MeV Van de Graaff accelerator to study internal-conversion electrons produced by proton and deuteron bombardment of target nuclei in the mass range $25 \leq A \leq 40$. While yields are expected to be rather low, it is felt that valuable information on nuclear levels can be obtained. Early in 1965, the spectrometer will be set up with the new ARL 8-MeV ICT Tandem Accelerator. It is anticipated that the higher-energy, greater-current capacity, and ion-source versatility will provide a unique capability for internal-conversion electron studies. ★

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the accuracy of positions of *CELESTIAL* bodies

MAJOR B. R. AGINS, Directorate of Mathematical Sciences, AFOSR

Recently, a survey was made at the AFOSR-sponsored Research Center for Celestial Mechanics by Dr. Dirk Brouwer and Dr. G. M. Clemence to determine the accuracies of the positions of stars and planets.

The accuracy of star positions is currently expressed by a mean error of the order of 0.10 seconds of arc in either coordinate for the best observed stars. For all stars brighter than about the 9th magnitude in the northern hemisphere, positions with mean error not exceeding 0.25 seconds will soon be available. The uncertainty in the southern sky is considerably higher, with mean error of the order of 0.3 to 0.7 seconds of arc. A reobservation of the southern hemisphere is about to be undertaken and, in the course of the next 10 years, these accuracies should approach those of the northern hemisphere.

The accuracy of the planetary positions is potentially the same as that of the star positions. For Mercury and Venus the mean error can be reduced to an estimated 0.3 seconds of arc. The new theory of Mars motion by Dr. Clemence should be capable of giving the heliocentric position with an uncertainty of less than 0.1 second of arc in each coordinate. For Jupiter, Saturn, Venus and Neptune the uncertainty is of the general order of 0.2 seconds of arc.

These figures are based on the General, Fundamental and Zone catalogues, with improvements and corrections available or about to become available, and on the recent work of Clemence, Duncombe, Brouwer and Eckert. ★

elementary, my dear Watson, elementary

(ELECTROMAGNETIC THEORY & THE WATSON TRANSFORMATION)

CAPTAIN JOHN F. GANDER
Directorate of Mathematical Sciences, AFOSR

The system of radiation and detection of signals conveying information, and their propagation as electromagnetic waves through space, is a branch of the art and industry of telecommunication. To bring the idea closer to home base, it is that indispensable tool that the Air Force continuously depends on in the performance of its over-all operational mission. For where would SAC, TAC, ADC, and the Air Force as a whole be without radar, radio and a variety of other communication media? However, these communicating devices are all too often taken for granted, especially by those not intimately associated with communication theory. More often than not, too little is given too late to the practical considerations of this vast and complicated subject, not to mention the lack of consideration "from those in the know" that the all-important theoretical aspects of the subject enjoy.

Fortunately, however, the situation is not as bad off as it could be, thanks to a little lemma (that's a mathematical theorem intellectually obvious to a mathematician after devoting the greater part of his life mastering the imbodied theory) published in 1918 by G. N. Watson. Since that time, many studies have been made of what is now called the Watson transformation. A recent paper entitled "Analysis of the Watson Transformation" by Professor W. Magnus and Mr. E. Fischer* of New York University (prepared under AFOSR-Mathematics Division support), considers what solutions can be expanded into a series of functions to which the Watson transformation should lead. The importance of such research is immediately realized when one considers that one of the basic problems of electromagnetic theory is to calculate the fields scattered and, in particular, reflected by obstacles of all sizes and shapes. To the "man in blue" this is the radar problem. He wants to detect a missile, an airplane, or a target; and the shapes, not to mention the sizes, of these various objects vary considerably. He especially wants to know how much signal is returned when a specified signal impinges off one of these obstacles so that he can tell how much signal strength the receiving antennas will be able to pick up (ultimately, what type of a scope picture he will get).

These are basic problems of diffraction theory and, in solving them, the Watson transformation plays a paramount role. It permits one to convert a rather complicated series solution of the problem into a much nicer series which converges more rapidly (this is synonymous with more accuracy). However, the Watson transformation is a rather sensitive mathematical process; and one has to examine the situation rather carefully in which it is used to determine if the transformation has been correctly applied.

There are many mathematical questions here, and it is extremely important that the mathematics of this transformation be thoroughly studied and understood so that we can tell where it can be used with confidence. Professor Magnus and Mr. Fischer, in their recent publication, take another bold step in this direction by giving a much clearer picture of when we can expect the Watson transformation to lead to a proper alternative solution to our original problem.

Such research is not just "pure" mathematics created to fill some journal that will gather dust on the lofty shelf of sophisticated science. In solving such types of problems theoretically, we are not only able to predict what will happen in actual situations where one must know what to expect, but we also save endless time, money and manpower by making and testing the design theoretically beforehand. If a person were to design a system by relying only upon some rough physical idea of what its performance might be, he would certainly waste time, manpower and material. Even after having built a satisfactory system, he would still not know whether he had done as well as possible. Only theory can indicate the full range of possibilities, so that one can select the optimum design. Elementary, my dear Watson--elementary. ★

** Fischer, E. and W. Magnus, "Analysis of the Watson Transformation."*

millimeter-wave propagation

DR. EDWARD E. ALTSHULER and MR. LEO KEANE, Micorwave Physics Laboratory, AFCRL

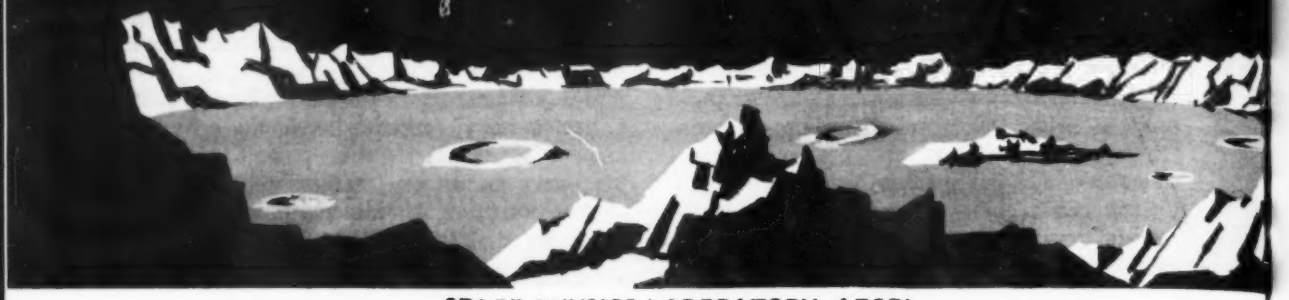
Nearing completion on Prospect Hill in Waltham, Mass., is a major new AFCRL field site. The dominant installation on the site is a high-precision, 29-foot dish to be used for millimeter-wave research. The antenna, which will use a maser pre-amplifier in its receiving system, is designed to operate at frequencies in the 35,000 Mcps region. Primarily designed for communications research at millimeter wave lengths, the antenna will also be used for research in radio and radar astronomy. The high-precision dish was placed on the antenna mount in late May.

Initial work with the antenna will be concentrated on atmospheric limitations to surface-to-space communications. Attenuation and refraction properties of millimeter waves are of primary interest. Associated with the facility will be a transmitting station located 10 miles away in Sudbury, Mass. Most of the research will involve propagation studies over this 10-mile propagation path.

Because of the very short wave lengths used, the reflecting surface of the antenna must be contoured to within very narrow tolerances. Segments making up the surface of the dish can be individually adjusted to within plus or minus .012 inch of a true parabola. The antenna is expected to have a gain of 68 db, a half-power beamwidth of .06 degrees, first sidelobes below -21 db, and sidelobes outside the region .5 degrees from the main beam below -55 db. The antenna turns on an azimuth elevation mount with an 18-bit, digitally controlled drive system. Pointing accuracy is maintained to better than plus or minus .015 degrees even under operational conditions of 30-knot-wind loads with thermal stresses due to solar heating and during inertial loads due to acceleration.

The antenna has a low noise receiver consisting of a traveling wave maser preamplifier, and will be tunable over a frequency range from 34,500 to 35,500 Mcps. The complete receiving system is expected to be operational by early 1965. Future plans are to add a 35,000-Mcps high-power transmission system to the facility and a 15,000-Mcps radar and radiometric system. The over-all performance of the antenna system should equal or exceed that of any other similar system from the standpoint of pointing accuracy, sensitivity and resolution.

LUNAR-SURFACE COMPOSITION



SPACE PHYSICS LABORATORY, AFCRL

On the 26th of February, 1964, two AFCRL scientists made unique observations of the moon, using for the first time a technique which may lead to the determination of compositional differences on the lunar surface from an earth-based observatory.

Drs. G. R. Hunt and J. W. Salisbury of the Lunar-Planetary Research Branch, Space Physics Laboratory, AFCRL, constructed a spectrometer capable of recording in an infrared spectral region previously unexplored in lunar research. This they coupled to the 42" telescope at Lowell Observatory in Flagstaff, Arizona. Their observations on the night of 26 February showed a difference in the mid-infrared spectral emission of lunar features which is probably due to a difference in composition.

The molecular vibration frequencies of silicate rocks and minerals (of which the earth's surface is principally composed) all occur in the mid- or far-infrared, at wave lengths longer than 8 microns. However, the majority of spectral information concerning such materials, i.e., the characteristic frequencies which are diagnostic of composition, is contained in two regions centered near 10 and 20 microns. The grouping of such data is illustrated in Figure 1, which presents the infrared-reflection spectra of several representative polished rock samples. Additional data is of course obtainable by extending the range into the far-infrared; but, for lunar observations, the limit to which detectable energy is available does not extend far beyond 40 microns.

For the observation of infrared-emission spectra of extraterrestrial bodies, it is fortuitous that there exist two atmospheric windows which largely coincide with the spectral regions of interest. They are the well-known and widely utilized 8-14-micron window, and another partial window which occurs at 16-24 microns. These windows are indicated in Figure 2 by the unshaded areas. Superimposed on these windows is the emission spectrum of quartz. The fact not generally appreciated is that the absorption in the 16-24-micron region is entirely due to water vapor. It seemed likely that the low moisture content of the air above Flagstaff, Arizona, would make it possible to obtain emission spectra from the moon in this region.

The emission from the moon has been quite extensively studied through the 8-14-micron window. Observations have been generally of 3 types:

(a) Spectral scanning of the whole disc during full moon - (e.g., Adel, A., Astrophysical Journal, 103, 19, 1946).

(b) Temperature measurements involving scanning the lunar surface with a fixed spectral range (radiometric measurements) during full moon - (e.g., Goeffrion, A.R., M. Korner and W.M. Sinton, Lowell Observatory Bulletin No. 106, 15 pp., 1960).

(c) Observation of lunar features during rapid cooling during eclipses to observe variations in thermal properties - (e.g., Saari, J.M. and R.W. Shorthill, Icarus, 2, No. 2, pp. 115-136, 1963).

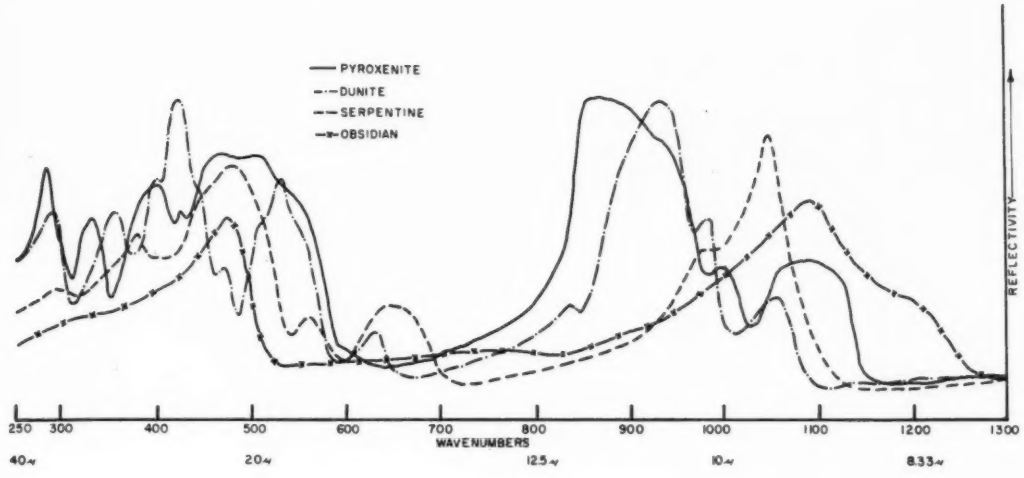


Figure 1 - Reflection spectra of polished rock samples recorded on Perkin Elmer Model 521 spectrophotometer. Angle of incidence 13°.

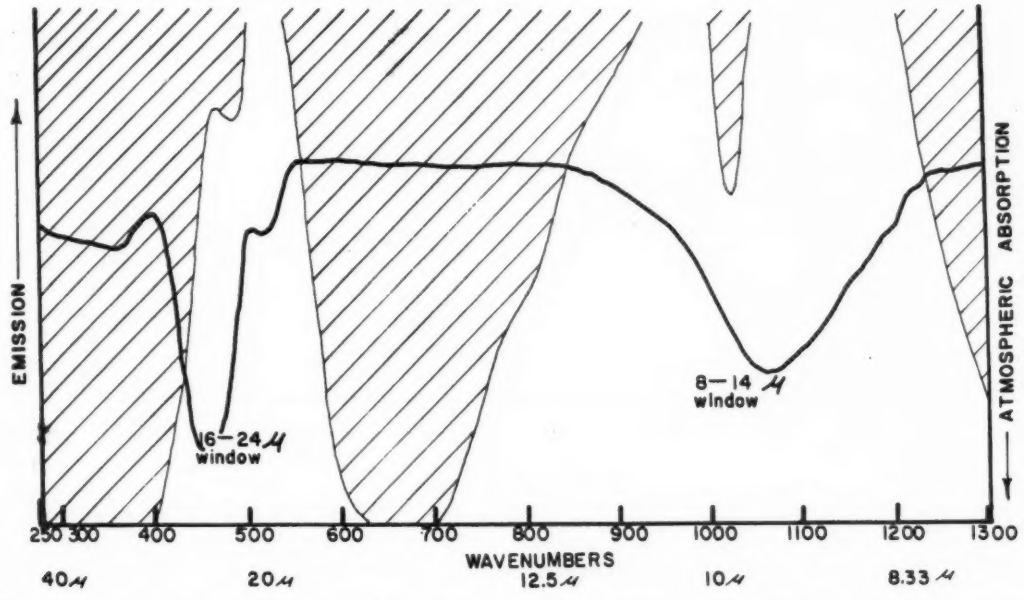


Figure 2 - Emission spectrum of Brazilian Quartz (black line), superimposed on atmospheric absorption spectrum. The relative intensities of transmission through the 16-24-micron window are exaggerated.

No previous observation of the moon through the 16-24-micron window is known. Four lunar features, viz., Central Highlands, Serenitatis, Copernicus and Tycho, were selected by Hunt and Salisbury and spectrally scanned through the 8-14 and 16-24-micron atmospheric windows with a sample size on the lunar surface of approximately 50 X 300 miles.

In Figures 3 and 4, the spectra obtained through the 16-24-micron window are shown at different amplifier gains. It is immediately obvious that the Tycho emission is much less than the other 3, but that there are also over-

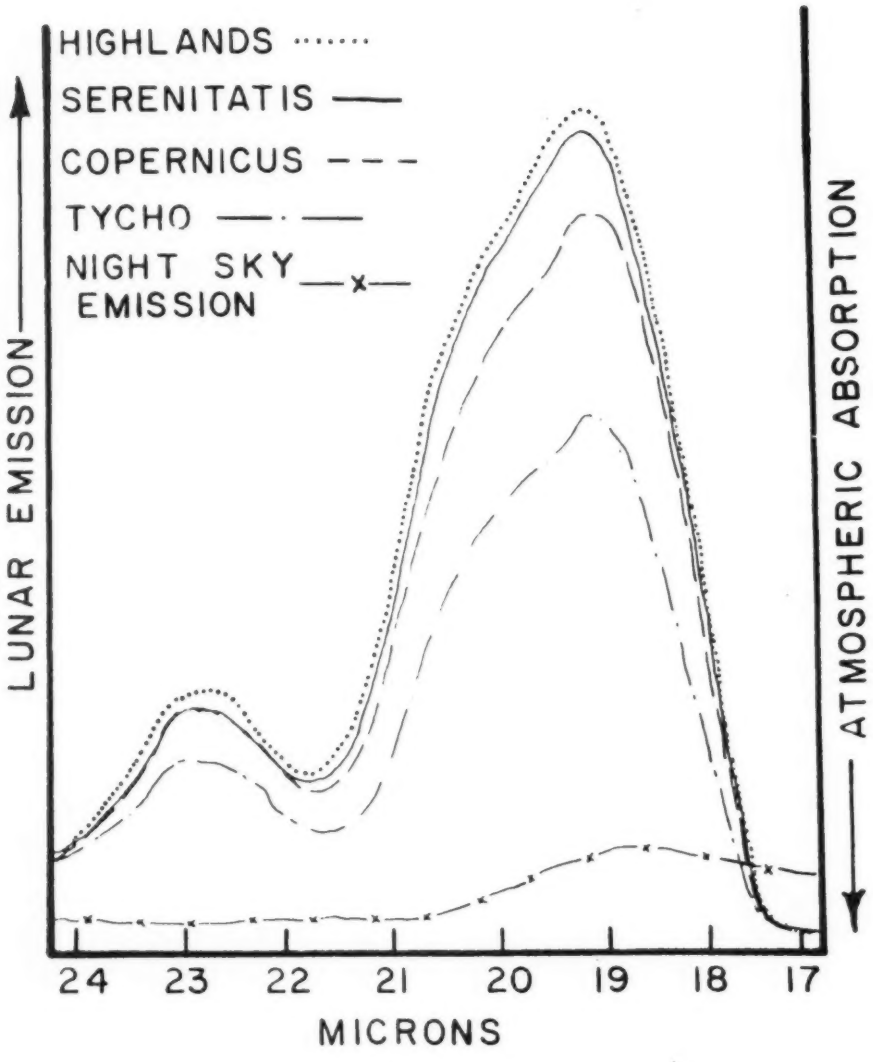


Figure 3 - Emission spectra of lunar-surface features through the 16-24-micron window. Slits 2 mm, amplifier gain 1.5.

all differences among the other 3. Most important in this region is the obvious difference between Copernicus and Serenitatis. The intensity of emission from Copernicus is less than from Serenitatis at the 11-micron peak, while it is more at the 23-micron peak. This indicates a difference in spectral response and thus in composition between the two lunar features or, in fact, between Copernicus and the other three. Since we are concerned here with differential spectroscopy, it would be highly conjectural to attempt, on the basis of these preliminary observations, to identify the compositional anomaly causing the difference. A laboratory program is in progress to study emission spectra of prob-

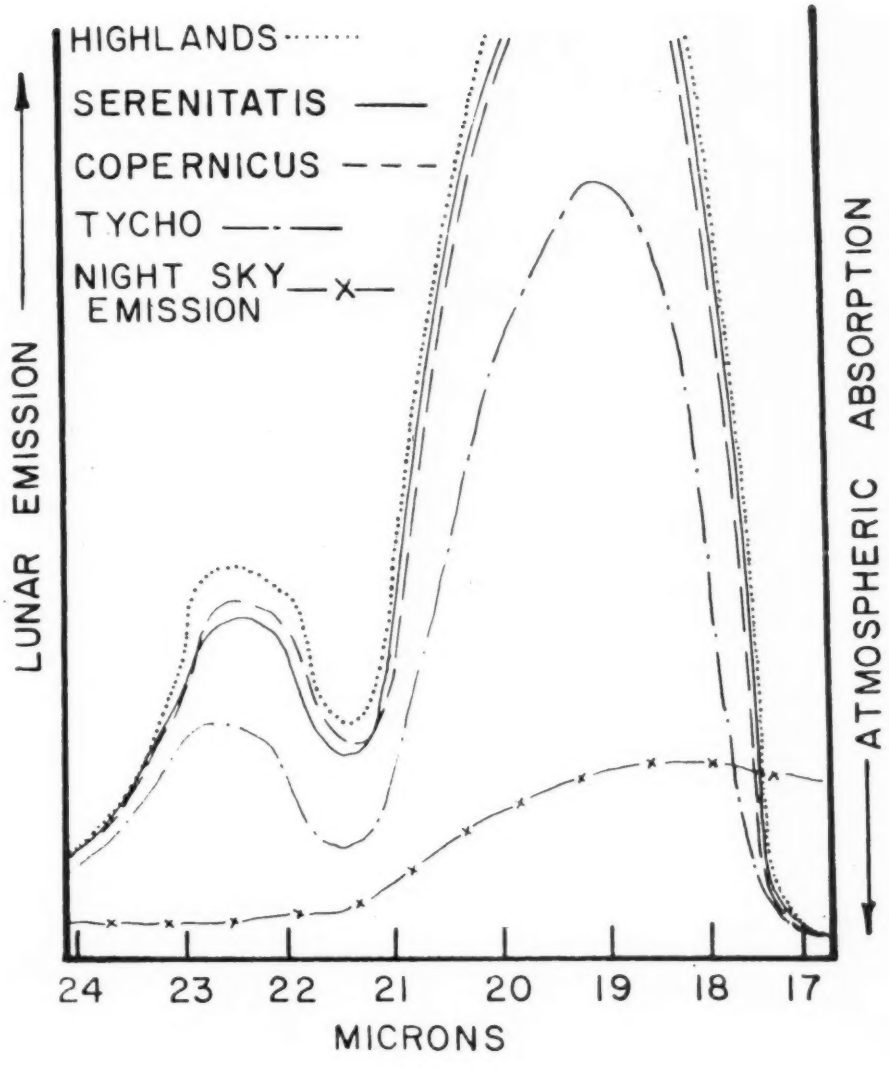


Figure 4 - Emission spectra of lunar-surface features through the 16-24-micron window. Slits 2 mm, amplifier gain 2.5.

able lunar materials in the 16-24-micron region; and more detailed measurements of spectral emission from various parts of the moon are being made in both atmospheric windows. This work should make possible the identification of the suspected compositional anomaly associated with Copernicus, as well as of others that may be found. In the interim, the AFCRL scientists report the unusual potential of the 16-24-micron window for compositional study of the moon from the surface of the earth. At the same time, observations of lunar spectra from a balloon-borne telescope will be attempted in order to obtain full spectral information relatively unmodified by atmospheric transmission. ★

OAR profiles

Mrs. Helen Reed Baker is a physicist in the Ionospheric Propagation Branch, Upper Atmosphere Physics Laboratory, AFCRL. She has a B.A. in Physics from the University of Maine, Orono, Maine (1949), and has taken graduate courses in theoretical and mathematical physics at Northeastern University, Boston, Mass. She has done physics research at MIT's Research Laboratory of Electronics, and has been a microwave development engineer for Raytheon, Bomac Laboratory for Electronics, General Communications Corporation. Presently, at AFCRL, Mrs. Baker is conducting research in the forward-scatter program, and carrying on studies in the general field of ionospheric ray tracing.

Mr. Gerald M. Daniels, a research physicist in the Ionospheric Propagation Branch, Upper Atmosphere Physics Laboratory, AFCRL, is presently studying ionospheric electron-density profiles, especially along the 25° W meridian, as part of a ray-tracing program. He has done field work in the 1962 series of high-altitude nuclear tests, and has studied the artificial aurorae created by these tests. Mr. Daniels has a B.S. degree in Physics with High Honors from Northeastern University (1956), and an M.S. degree in Physics from the University of Michigan (1957). He has completed requirements for the Doctorate at MIT except for the dissertation.

Reading from left to right are Mr. Roger A. Van Tassel, Dr. Graham R. Hunt, and Dr. John W. Salisbury, all with the Lunar-Planetary Research Branch, Space Physics Laboratory, AFCRL.

Mr. Van Tassel is a research chemist currently working on infrared spectroscopy of the moon and planets from an astronomical balloon-borne telescope, and development of the associated scientific instrumentation. He has a B.A. from Wesleyan University, Middletown, Conn., and has completed his course requirements at Tufts University for a Ph.D.

Dr. Hunt is a physical chemist whose current work involves application of spectroscopic techniques to the study of probable lunar-surface materials, their dielectric constants, and the effects of radiation upon them. He has a B.Sc. (Hons) (1952), an M.Sc. (1954) and a Ph.D. (1958), all in Physical Chemistry, and all from Sydney University, Sydney, N.S.W. Australia.

Dr. Salisbury, as Chief of the Lunar-Planetary Research Branch, directs a program of research concerned with the nature of both lunar and planetary environments. His own research is concerned primarily with the origin of lunar-surface features and the composition and nature of lunar-surface materials. (Some of this work, as conducted by Drs. Salisbury and Hunt, is described in "Lunar-Surface Composition" in this issue of the Review.) Dr. Salisbury has a B.A. in Geology Magnum Cum Laude from Amherst College, Amherst, Mass. (1955), and an M.S. in Geology (1957) and a Ph.D. (1959), both from Yale University, New Haven, Conn.

All three scientists have a number of publications to their credit.

Mr. Rupert S. Hawkins, a scientist with the Meteorology Laboratory at AFCRL, is presently studying terrestrial radiation measurements obtained from earth-orbiting satellites. One objective is to interpret the data in terms of important atmospheric parameters. He received a B.A. degree in mathematics from Berea College, Berea, Kentucky, and an M.S. degree in meteorology from Florida State University, Tallahassee, Florida.

NEW FEED SYSTEM FOR SPHERICAL ANTENNAS

DR. EDWARD E. ALTSHULER
Microwave Physics Laboratory, AFCRL

A new-type antenna feed--a line-source phased array--has been developed by AFCRL. Although the AFCRL development is most directly applicable to the recently completed Arecibo Radio Telescope in Puerto Rico, the technique can be applied to any large-aperture spherical antenna. The feed system is not intended as a replacement for the present Arecibo line-source feed, but as a supplemental feed for operation at the 1420-Mcps hydrogen-line frequency.

Since a spherical reflector does not have a single focal point (in contrast to a conventional paraboloidal antenna), it cannot be efficiently illuminated with a point-source feed. Work at AFCRL on the focusing properties of spherical reflectors dates back to 1950; and it was from this work that the Arecibo spherical configuration evolved. It has been shown that rays reflected from a spherical reflector focus along a line, and that the effects of this spherical aberration can be minimized by properly controlling the phase along a line-source feed. Large, fixed spherical antennas have one great advantage over a comparable paraboloidal antenna--they can be scanned over a much larger angle.

The new AFCRL feed is 27.72 feet in length and is designed to operate at 2840 Mcps. By simply doubling its length, it can be scaled for the hydrogen-line frequency. It consists of an array of 247 pairs of monopoles coupled to a rectangular wave guide. The phase velocity along most of the line source is controlled by tapering the wave-guide width. At the beginning of the line-source feed, phase velocity approaching that of free space is required, and this is obtained using a slow-wave periodic structure of cylindrical posts. The amplitude distribution across the spherical reflector is controlled by the monopole penetration into the wave guide. The advantage of this design is that amplitude and phase can be adjusted precisely, and efficient illumination of the spherical reflector can be achieved. This feed has been tested and a report, "A Monopole Phased Array Feed for Spherical Reflectors," AFCRL No. 64-291, has been issued. ★

AFCRL-BTL *COOPERATIVE SPEECH PROGRAM*

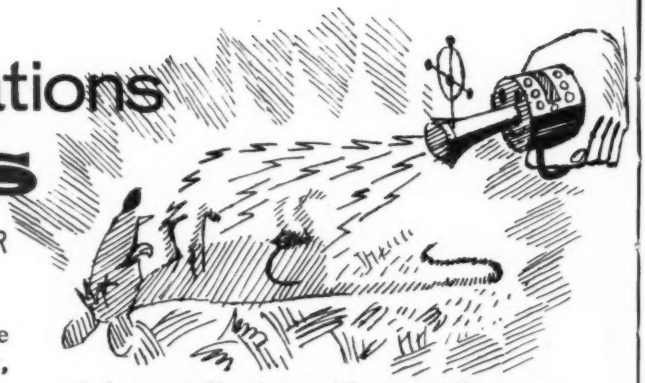
PHILIP LIEBERMAN Data Sciences Laboratory, AFCRL

Speech synthesis--that is, the recreation of vocal sounds by electromechanical means--is one of the basic parts of speech research. The goal is to reproduce speech with fidelity and naturalness. What AFCRL and other laboratories hope to overcome is the mechanical quality so often associated with speech synthesizers.

For the past year or so, AFCRL has made high-speed color movies of the movement of the vocal cords. From these movies, the glottal openings during speech are analyzed--an analysis which requires the plotting of some 20,000 data points for each second of speech. But this analysis is only a part of an overall analysis process that must be completed if we are to learn what aspects of glottal activity are relevant for the preservation of natural-voice quality and speaker identification. In order to synthesize speech from the glottal-opening wave form, we have first to compute the volume velocity of the air flow through the glottal opening.

The Bell Telephone Laboratories, in a kind of exchange agreement, taking AFCRL's data on glottal-area functions, will compute the volume-velocity functions and make the data available to us. This cooperation on a program of equal interest to AFCRL and to the Bell Telephone Laboratories will speed up the AFCRL program by six months. Also, the data will be provided without cost. ★

military applications of **lasers**



CAPTAIN CHARLES M. JONES, USAFR
Optical Physics Laboratory, AFCRL

The primary advantages of lasers accrue from their properties of intense power, monochromaticity, narrow beams, and coherent output. These properties are found in all three types of lasers: the gas laser, the optically pumped solid, and the electrically pumped solid. At present, the optically pumped solid or ruby laser provides the most intense outputs with 500-megawatt pulses containing about 1500 joules of energy having been observed. The gas laser and electrically pumped solid (solid-state) laser provide continuous laser action, and the solid-state laser can be modulated.

A large number of uses for lasers have been reported. North American Aviation has reported a laser dental drill, one manufacturer uses a laser to precision-cut resistors to .05% tolerance, and the uses of a laser for eye surgery have been widely publicized. Hughes Aircraft Co. has demonstrated a laser radar, voice has been transmitted 118 miles over a laser beam, and the use of lasers for ranging and tracking of missiles and space vehicles is being considered. It has been suggested that a laser will make possible an electro-optical digital computer with tremendous speeds of computation, and that a laser will permit precision spot welding of metal whiskers for microminiature circuits. Also, a laser experiment consisting of the transmission of a 30-sec. message from Gemini via a hand GaAs laser is being considered.

Russia has reported a gamma-ray laser for which Boeing applied for a patent over a year earlier. A study of the destructive effects of coherent light and intense light on cell development and plant growth is being undertaken. The laser provides a high-energy source for investigating interactions between photons and matter.

To be sure, military benefits from many of these applications will eventually accrue indirectly, since the civilian economy must provide support for all military capabilities. Laser technology requires advances in crystal growth, materials research, machining techniques, precision mechanics, and many other areas. From these efforts, it can be expected that many side benefits will accrue. Once laser phenomena are better understood, advances in areas seemingly little related may be possible.

The direct military benefits of laser technology will necessarily be less numerous than those listed above. Direct military benefits may be defined as those that contribute to more effective military operations. In this category, we might include contributions to such things as weaponry, communications, command control, weapon carriers such as aircraft or missiles, detection and tracking, and sensors. To determine military benefits, then, we have only to consider how narrow beams of coherent light with intense power might contribute to these military interests.

A highly touted use for the laser has been the "death ray." While the laser does provide intense power, the total energy delivered over a significant time interval is still much less than that required for a true "death ray." The ruby laser delivers 500 megawatts, but only for a microsecond or so; the total energy of 1500 joules reported to date is several orders of magnitude below that required to vaporize and destroy a critical part of an enemy weapon. The absorption of the atmosphere will further attenuate these powers even over short distances. One author has suggested that perhaps the "death-ray" effect of the laser should be more appropriately referred to as blinding.

The most immediate use for the laser appears to be its application to communications. Within the past few years, the useable frequency spectrum has become increasingly crowded. Voice and digital data band widths of a few thousand cycles are easily accommodated over telephone circuits. Television, however, requiring a 4-megacycle band width, must have its own circuits for transmission. The costs of ocean cable make it attractive to use multiplexing techniques to allow use of more voice and teletype circuits over a single cable. To increase the useable band width, the trend has been to go to higher and higher radio frequencies which are less crowded and which can provide the band width required. Coupled with the communications-interference problem with radio frequencies has been the military need for security. Using narrow beam widths reduces interference and increases the security for point-to-point communications. To obtain the narrow beams, a laser parabolic reflector has been used. Tropospheric scatter communications, for example, have used 60-foot diameter antennas and kilowatts power to provide a few voice circuits over a distance of 200-300 miles.

The laser readily produces an extraordinarily narrow beam, capable of being modulated with many megacycles band widths, and with no large unwieldly antennas. The laser seems a natural answer to many of the communications problems that exist with point-to-point communications. It has been said that a single laser beam could carry all the television channels in the world, if the multiplexing techniques could be developed. The problem remaining is to develop the modulation and multiplexing techniques required.

The laser is <u>not</u> the answer to all communications problems. It does not overcome the line-of-sight limitations, it does not provide a broadcast capability, and it is attenuated by the atmosphere. It is frequently suggested as a solution to many space communications problems for these reasons. For telemetering satellite data, however, the satellite must be tracked very accurately for reliable communications. The laser, of course, may also be used to provide the tracking signal.

The laser radar may offer additional military potential by providing very accurate tracking. The narrow beam, however, signifies that a means of acquiring the target will be required to first detect the target before it can be tracked. The contradictory requirements for detection or search <u>and</u> tracking also obtains with present radar techniques.

Within the five years since the laser was first demonstrated, much progress has been made. The most useful application of the laser is perhaps yet to come. As with any new phenomena, the applications first envisioned may well be the least of the benefits that will come from the laser. Just as the submarine was first thought of as a way of avoiding ocean storms, and the aircraft was first considered as primarily a reconnaissance tool (who was it that said during World War I that there was no need for any aircraft to fly more than one day's march ahead of the infantry?), just so the usefulness of the laser to the military has probably yet to be envisioned. ★

This paper was written by Captain Jones while on two weeks' active duty at AFCRL.

ATMOSPHERIC-DENSITY EXPERIMENT

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

A two-stage, solid-propellant Astrobee 200 rocket was launched on 9 June 1964 from the Pacific Missile Range. The rocket's pay load was designed to obtain atmospheric-density information in the 95 to 160 km region. The rocket ejected a 9-foot inflatable sphere. Aerodynamic drag on the sphere was measured by three linear accelerometers carried within the sphere.

The sphere was ejected on the upward leg of the trajectory. It was completely inflated and stabilized by the time it reached its peak altitude. From that altitude, the sphere was in free fall except for atmospheric drag. Drag data were telemetered to the ground by a transmitter also contained in the sphere.

The sphere, its accelerometers and transmitter, weighed only 10 pounds. AFCRL project scientist for the successful experiment was Gerard A. Faucher. ★

An empirical relationship between the Mach, Reynolds, and Knudsen numbers

1st LT WILLIAM G. REINECKE
Hypersonic Research Laboratory, ARL

In any mathematical analysis of a physical problem, nondimensional groups of variables and parameters appear. These groups are quite important because they indicate which phenomena must be considered in the analysis and which may be neglected. Among the most important of these parameters in aerodynamics are the Mach number M and the Reynolds number Re. The Mach number is, of course, the ratio of the gas speed u to the local speed of sound a, and represents the ratio of the amount of directed, or kinetic, energy in the gas to its random, or thermal, energy. The Reynolds number is the ratio of the dynamic pressure of the gas ρu^2 (ρ is the local density) to a characteristic viscous shear stress $\mu u/x$ (where x is a characteristic length and μ is the viscosity) and is a measure of the importance of viscous effects in the flow.

With the advent of high-altitude flight, a new parameter, the Knudsen number Kn, has become important to aerodynamicists. This number is the ratio of the mean free path of the gas λ to a characteristic dimension x, and indicates, among other things, whether the gas may be considered a continuum. It is vital that the investigator have some a priori knowledge of this parameter, since his whole approach to a problem will vary significantly if the gas cannot be considered a continuum. Now the mean free path is closely associated with the transport properties of the gas and, hence, with the viscosity. This suggests that there may exist a relation between Re and Kn. Indeed, this is the case. The relation is very complex and depends upon many factors, including, for example, the shape of the body around which the gas is flowing. Below, we shall develop one simple relation between Re and Kn.

The mean free path λ is defined as the ratio of the characteristic speed of the gas molecules divided by their collision frequency. In reference 1, Muchenfuss points out that, since the collision frequency is independent of the frame of reference of the observer while the characteristic speed is not, then λ must depend upon the observer's frame of reference. Specifically, Muchenfuss shows that, for large Mach numbers, λ is proportional to its value as measured by an observer moving with the gas multiplied by M. Finally, we know from simple kinetic theory that in a gas without mean mass speed

$$\mu \sim a \lambda \rho .$$

But this λ is the mean free path measured by the observer moving with the gas. So in the frame of reference in which the gas as a whole is moving

$$\mu \sim \frac{a \lambda \rho}{M} .$$

We may now rearrange this proportion to give

$$\frac{M \cdot \frac{u}{a}}{\frac{\rho u^2}{\mu \frac{u}{x}}} \sim \frac{\lambda}{x} ,$$

or

$$\frac{M^2}{Re} \sim Kn.$$

This is the desired relation between Kn, M and Re.

The foregoing analysis has been very crude and many of the assumptions are demonstrably inaccurate. However, we may check it by calculating ρ, λ, and μ from various independent formulae and noting whether the value of Kn Re/M^2 is truly constant. This has been

done by the author in reference 2. It is shown that, over a large range of hypersonic (large M) wind-tunnel conditions, the value of Kn Re/M^2 in the test section varies only by a factor of four. This variation may seem large until we note that, in the same range, M, Kn and Re each vary by several orders of magnitude. Moreover, an analytical function

Kn = function (M, Re)

is derived in reference 2 by fitting the calculated data points by the method of least squares. This function matches the calculated points with a root mean squared error of less than five per cent. ★

References:

1. *Muchenfuss, C., "Mean-Free-Path Concept in Gas Dynamics," Physics of Fluids, Vol. 5, Nr 3, pp 165-168, February 1962.*
2. *Reinecke, W. G., "Charts for Use with Hypersonic Wind Tunnels," ARL 64-56, April 1964.*

cloudiness & the moon

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

There's really no known reason why cloudiness should be correlated with the phase of the moon. But records dating back to the early 1900's seem to show such a relationship. In one of the most complete analyses performed to date on possible lunar-cloudiness relationships, Iver Lund of AFCRL shows that, for certain seasons at certain localities, there is indeed a marked correlation. Statistically, there's only a remote possibility that the correlation found between cloudiness and different phases of the moon could occur by pure chance.

People have shown great interest in this matter since the publication in 1962 by Bradley, Woodbury and Brier of a study which indicated a positive relationship between rainfall and the lunar cycle. But Fred Ward of AFCRL reviewed this study last year and, (using some 1,000 dates of heaviest rainfall over a 92-year period in the Boston area), found no precipitation-lunar phase relationship. Lund's study, however, is not concerned with precipitation, but with presence or absence of clouds. "Cloudiness" can mean many things--fog, convective clouds, and complex frontal systems.

Lund's study covers 21,184 days of observations over a period of 58 years--1905 to 1962. Daily records of sunshine at each of 10 US cities made up this total data sample. These stations are: Boston; Tampa; Bismarck; Grand Junction, Colorado; Columbus, Ohio; Oklahoma City; San Diego; Columbia, Missouri; Seattle and Honolulu.

What are some results of this study? As might be guessed, the extent of the correlation varies from station to station and from season to season. The correlation for most stations is most pronounced in the spring and summer. In the fall and winter, some stations actually show a negative correlation. But if we combine all observations from all 10 stations used in the study for the entire 58-year period of observations, a definite correlation is still found.

Let's look at the way the data were analyzed. First, the average amount of cloudiness for a particular season was established. Then three-day periods were examined to see if the amount of sunshine for these periods was above or below the average for the season. We came up with simple plus or minus values for each three-day period; the degree of cloudiness within the period was not considered.

With this as the statistical basis, Lund found that, between the period of the new moon and the first quarter, there is less sunshine than average for the season. Between the first quarter and the full moon, the amount of sunshine is above average. Between the full moon and the last quarter, we again have less than average sunshine; and finally, between the last quarter and the new moon, sunshine rises above average. If

we plot this data for a 29.53-day lunar month, we have a model that describes a 2-period sine wave which moves alternately below and above the average center line. All stations, except for Honolulu, showed a strong relationship with this model for the spring and summer months.

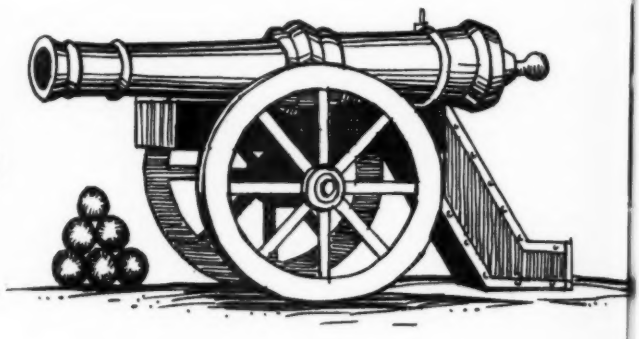
The analysis was done by computer. The data are now being examined using different statistical approaches. Future plans call for the analysis of weather data from three stations in Japan and two stations in Europe. Data will also be correlated with levels of solar magnetic activity.

Concerning results to date, it is difficult to give a precise level of statistical significance, that is, to state the odds of the observed correlations occurring by pure chance. The reason for this is that most of the continental US stations used in the study are interconnected from the standpoint of gross weather patterns. A weather pattern in Columbus, Ohio, for example, will often move eastward to show up in Boston a day or so later. But if we assume no interconnections of this sort, there would be only about one chance in 10,000 that the observed relationships occurred by pure chance.

If the relationship is a real one, how can it be explained? No one has provided a meaningful explanation. Variations in meteoric dust in the upper atmosphere and atmospheric tides produced by the moon have been suggested as possible contributing causes, but neither is very satisfactory. ★

ROCKETS and CANNONS

DR. NORMAN W. ROSENBERG
Upper Atmosphere Physics Laboratory
AFCRL



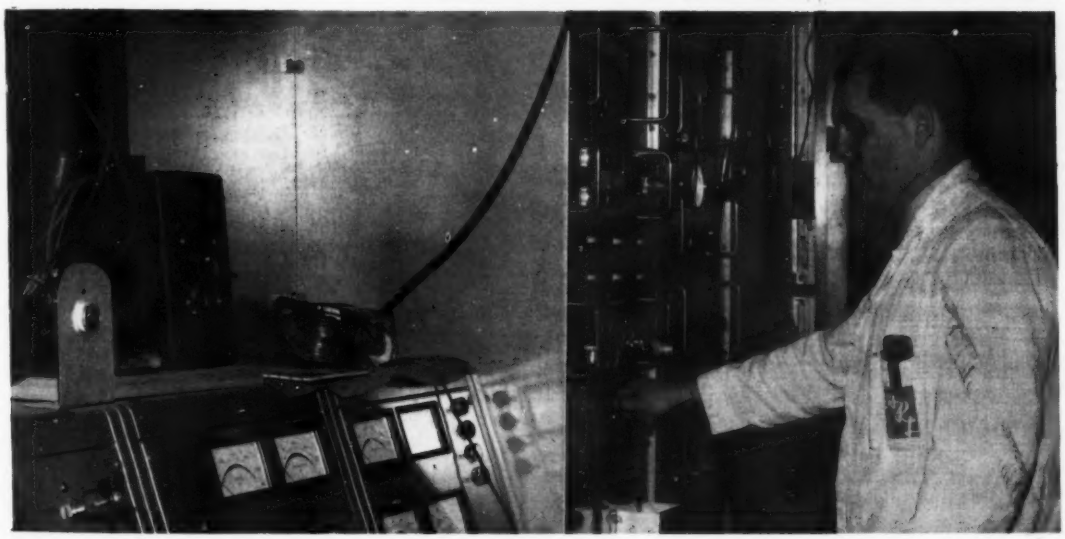
A projectile fired from a cannon may be able to carry sensors into the upper atmosphere at lower cost and with greater accuracy than rockets. During June and July, AFCRL participated in a series of 15 test firings to evaluate the technique. Called Project HARP for High-Altitude Research Program, the technique was developed by McGill University and the Army Ballistic Research Laboratories. It utilized a modified 16-inch naval gun to fire a 200-pound pay load to an altitude of about 160 km. Tests took place in the Barbados Islands.

AFCRL consulted in design of the 200-pound "bullets" which released five pounds of trimethyl aluminum (TMA) as a trail between 90 km and the 150-km bullet apogee. The glow from the TMA defined both vehicle trajectory and ambient winds by photography and triangulation.

Scientific objectives were to measure windshear patterns, turbulence characteristics and temperatures. AFCRL provided in-house temperature-measuring spectrometers, and arranged for cooperative observations by a University of Paris optics group, an ionosonde group from the National Bureau of Standards at Boulder, and a TV light-amplifier unit from Patrick Air Force Base. ★

ARL scientists seek new knowledge

1

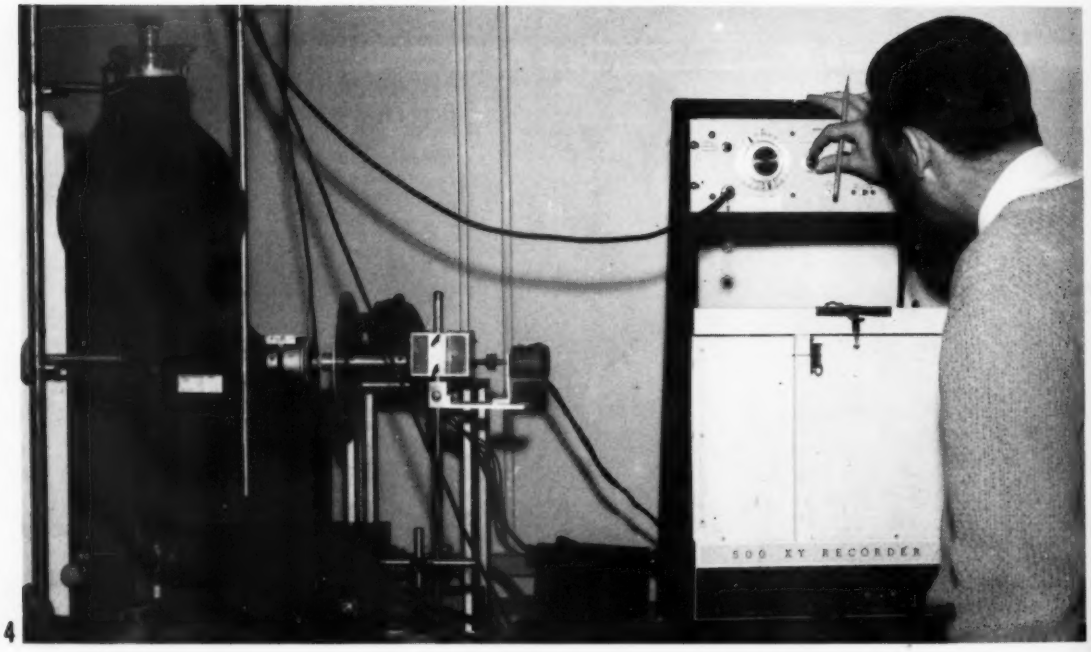


2

Photo 1 Mr. Radames K. H. Gebel of the Solid State Physics Research Laboratory, ARL, is shown with a scanner for spatial inhomogeneities of crystals. He has in hand a vidicon with a sealed crystal front next to an electronic image reproducer for observing inhomogeneities.

Photo 2 High-energy density plasma facility, with 1st Lt J. W. Birkeland of the Plasma Physics Research Laboratory, ARL.

3



4

Photo 3 Mr. Don W. Naas of the Solid State Physics Research Laboratory, ARL, inspecting crystal-growing furnaces.

Photo 4 Mr. Don C. Reynolds of the Solid State Physics Research Laboratory, ARL, operates apparatus used for studying exciton fine structure in photoconductivity.

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